



February 29, 1996

Dr. Louis Goodman  
ONR 322  
Office of Naval Research  
Ballston Centre Tower One  
800 North Quincy Street  
Arlington, VA 22217-5660

Dear Dr. Goodman:

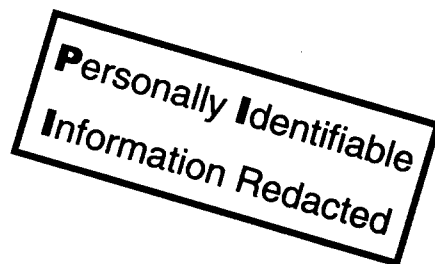
Enclosed please find three copies of Dr. Michael Brown's Final Technical Report for our ONR Contract No. N00014-91J-1279 entitled "Low-Order Nonlinear Ocean Dynamics".

We hope the report is satisfactory for your needs.

Sincerely,

A handwritten signature in cursive script that reads "Anne M. Hoey".

Anne M. Hoey  
Administrative Assistant



cc: Administrative Grants Officer, Regional Office Atlanta (1)  
Director of Naval Research Laboratory, Code 2627 (1)  
Defense Technical Information Center (2) ✓  
Office of Naval Research ONR 00CC1 (Patent)

Rosenstiel School of Marine and Atmospheric Science  
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DTIC QUALITY INSPECTED 1

ONR contract N-00014-91J-1279 Final Report

Title: Low-Order Nonlinear Ocean Dynamics

PI: Michael G. Brown (305)361-4640 phone  
RSMAS-AMP, Univ. of Miami (305)663-9652 fax  
4600 Rickenbacker Cswy  
Miami, FL 33149

Work on this contract focused on two topics which relate to low-order nonlinear ocean dynamics: 1) understanding the manner in which dynamical constraints - specifically, vorticity conservation or lack thereof - affect oceanic particle motion; and 2) assessing whether low-order behavior can be detected in the temporal evolution of large scale geophysical flows.

Work on the connection between vorticity dynamics and particle motion is summarized by Brown and Samelson (1994). The important result of this paper is that chaotic particle motion is precluded in two-dimensional incompressible flows which conserve vorticity (or potential vorticity) provided the vorticity distribution is nonuniform. This result has important implications for numerical and analytical studies of chaotic advection in geophysical flows (because the assumed flows are generally prescribed without regard to any associated vorticity dynamics) and for the interpretation of oceanic float/drifter trajectories which seem to be chaotic.

Work on the search for low-order behavior in geophysical flows resulted in the development of a data analysis tool which we call "dynamic EOF analysis." Low order behavior is the type of behavior, possibly including chaos, associated with systems of a small number of generally nonlinear coupled ordinary differential equations. The new "dynamic EOF analysis" tool generalizes a technique developed originally to analyze time series in such a way that temporally evolving spatial fields can be analyzed. The purpose of this tool is to uncover underlying low-order behavior if it is present in a temporally evolving field. Application of this technique uncovered low-order behavior in SST anomalies in the eastern tropical Pacific (Bauer and Brown, 1992). For mid-latitude flows, however, no low-order behavior has been uncovered.

The publications listed below were produced with support from this contract.

Bauer, S. T., and M. G. Brown, 1992, Empirical low-order ENSO dynamics, Geophys. Res. Lett., 19, 2055-2058.

Brown, M. G. and R. M. Samelson., 1994, Particle motion in vorticity conserving 2-d incompressible flows, Phys. Fluids., 6, 2875-2876.

Brown, M. G., 1993, Chaos in ocean physics, in Proceedings of the Aha Huliko'a Hawaiian Winter Workshop on Statistical Methods in Physical Oceanography, P. Muller and D. Henderson (eds), SOEST Publication Services, 373-380.

Brown, M. G. and S. T. Bauer, 1993, Empirical low-order ocean-atmosphere dynamics, AGU Chapman Conference on Fractals, Chaos and Predictability in Oceanography and Meteorology, Galway, Ireland, Sept. 20-22. (Invited paper)

Brown, M. G., and R. M. Samelson, 1995, Particle motion in vorticity conserving, two-dimensional incompressible flows, European Geophysical Society, Hamburg, April 3-8. (Invited paper)

REPORT DOCUMENTATION PAGE			FORM APPROVED OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing the burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302 and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 29 Feb 1996	3. REPORT TYPE AND DATES COVERED Final 1 Oct 92 - 30 Sep 95	
4. TITLE AND SUBTITLE OF REPORT Low-Order Nonlinear Ocean Dynamics			5. FUNDING NUMBERS N00014-91J-1279	
6. AUTHOR(S) Dr. Michael G. Brown				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Miami/RSMAS 4600 Rickenbacker Causeway Miami, FL 33149			8. PERFORMING ORGANIZATION REPORT NUMBER: UM #668677	
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11. SUPPLEMENTARY NOTES: N/A			19960314 064	
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13. ABSTRACT (Maximum 200 words)				
<p>Work on this contract focused on two topics which relate to low-order nonlinear ocean dynamics: 1) understanding the manner in which dynamical constraints - specifically, vorticity conservation or lack thereof - affect oceanic particle motion; and 2) assessing whether low-order behavior can be detected in the temporal evolution of large scale geophysical flows.</p> <p>Work on topic 1 resulted in a proof that chaotic particle motion is precluded in two-dimensional incompressible flows which conserve vorticity (or potential vorticity) provided the vorticity distribution is nonuniform. This result has important implications for numerical and analytical studies of chaotic advection in geophysical flows and for the interpretation of oceanic float/drifter trajectories.</p> <p>Work on topic 2 resulted in the development of a data analysis tool which we call "dynamic EOF analysis" whose purpose is to uncover underlying low-order behavior, if it is present, in a temporally evolving field. Application of this technique uncovered low-order behavior in SST anomalies in the eastern tropical Pacific but not in mid-latitude flows.</p>				
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# REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause) (See Instructions on Reverse Side.)

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1a. NAME OF CONTRACTOR/SUBCONTRACTOR University of Miami		c. CONTRACT NUMBER N00014-91J-1279		3. TYPE OF REPORT (X one) a. INTERIM <input checked="" type="checkbox"/> b. FINAL	
b. ADDRESS (Include ZIP Code) P.O. Box 248106 Coral Gables, FL 33124		d. AWARD DATE (YYMMDD) 92 Oct 1		4. REPORTING PERIOD (YYMMDD) a. FROM 92 Oct 1 b. TO 95 Sep 30	

## SECTION I - SUBJECT INVENTIONS

5. "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR/SUBCONTRACTOR (If "None," so state)

a. NAME(S) OF INVENTOR(S) (Last, First, MI)	b. TITLE OF INVENTION(S)	c. DISCLOSURE NO., PATENT APPLICATION SERIAL NO. OR PATENT NO.	d. ELECTION TO FILE PATENT APPLICATIONS				e. CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER
			(1) United States (a) Yes	(2) Foreign (b) No	(1) Yes	(2) No	
NONE	Dr. Michael G. Brown						

9. ELECTED FOREIGN COUNTRIES IN WHICH A PATENT APPLICATION WILL BE FILED

1. EMPLOYER OF INVENTOR(S) NOT EMPLOYED BY CONTRACTOR/SUBCONTRACTOR	2. Foreign Countries of Patent Application
(1) (a) Name of Inventor (Last, First, MI)	
(b) Name of Employer	
(c) Address of Employer (Include ZIP Code)	

## SECTION II - SUBCONTRACTS (Containing a "Patent Rights" clause)

a. NAME OF SUBCONTRACTOR(S)	b. ADDRESS (Include ZIP Code)	c. SUBCONTRACT NO.(S)	d. DEAR "PATENT RIGHTS"		e. DESCRIPTION OF WORK TO BE PERFORMED UNDER SUBCONTRACT(S)	f. SUBCONTRACT DATES (YYMMDD)	
			(1) Clause Number	(2) Date (YYMM)		(1) Award	(2) Estimated Completion

## SECTION III - CERTIFICATION

(Not required if Small Business or Non-Profit organization) (X appropriate box)

7. CERTIFICATION OF REPORT BY CONTRACTOR/SUBCONTRACTOR		c. I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all "Subject Inventions" have been reported.	
8. NAME OF AUTHORIZED CONTRACTOR/SUBCONTRACTOR Diaz-Piedra, Aida Associate Controller		d. SIGNATURE Diaz-Piedra	
		e. DATE SIGNED 3/5/94	